IOS and DPM: Simulation tools for exploring and understanding factors influencing Central Valley Chinook salmon populations

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What data is available for winter run Chinook salmon?

Life Stage	Location	Timeseries of abundance data available?
Eggs	Up-river	
Fry	Up-river	X
	Mid-river	
	Delta	
Parr	Up-river	X
	Mid-river	
	Delta	
Smolts	Mid-river	
	Delta	
Smolts	Bay	
Sub-Adult	Ocean	
Adult	Ocean	
	Spawners	X

What data is available for winter run Chinook salmon?

Life Stage	Location	Timeseries of abundance data available?	Mechanistic (short term) studies available?
Eggs	Up-river		X
Fry	Up-river	X	X
	Mid-river		
	Delta		
Parr	Up-river	X	
	Mid-river		X
	Delta		X
Smolts	Mid-river		X
	Delta		X
Smolts	Bay		X
Sub-Adult	Ocean		X
Adult	Ocean		X
	Spawners	X	

What data is available for winter run Chinook salmon?

Life Stage	Location	Timeseries of abundance data available?	Mechanistic (short term) studies available?	Combined
Eggs	Up-river		X	X
Fry	Up-river	X	X	X
	Mid-river			
	Delta			
Parr	Up-river	X		X
	Mid-river		X	X
	Delta		X	X
Smolts	Mid-river		X	X
	Delta		X	X
Smolts	Bay		X	X
Sub-Adult	Ocean		X	X
Adult	Ocean		X	X
	Spawners	X		X

Statistical Models   Simulation Models

$$L\left(\theta \mid R_k, n_j\right) \propto \prod_{j=1}^{912} \pi_j^{n_j}$$
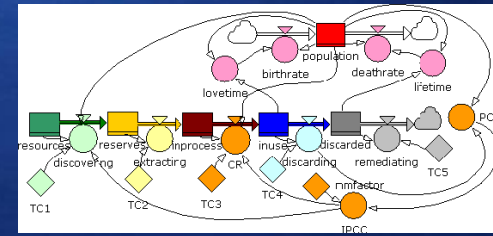

Statistical Models

- Parameter values obtained by fitting model to available historic data

- Fewer parameters

- Identify critical factors driving past population trends, provide "real world" predictions

- Static

Examples:
Jolly-Seber mark-recapture
  Generalized linear
   Bayesian nonlinear hierarchical

Simulation Models

- Parameter values based on empirical, statistical, and theoretical data

- More parameters

- Experimental system, compare relative performance of simulated management actions

- Adaptable, modular

Examples:
    bioenergetics
       predator-prey
          individual-oriented life cycle

Concepts

Purpose of our simulation models:

- Formalize and clarify thinking
- Allow comparison (relative) between alternative management actions
 - *not* predictions of past or future population trends

Concepts

Attributes of our simulation models:

- <u>Intuitive</u>: data and relationships familiar to biologists

- <u>Mechanistic</u>: emphasize dynamic response of fish to alternative management scenarios

- <u>Transparent</u>: logic and functional relationships transparent and accessible

- <u>Adaptive</u>: Model can be easily modified to include new data or relationships

Simulation Models Related to Operations and RPAs

- Juvenile Production Estimate (JPE) Model
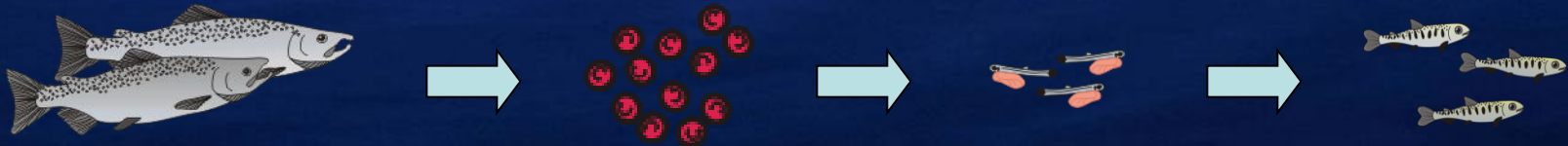
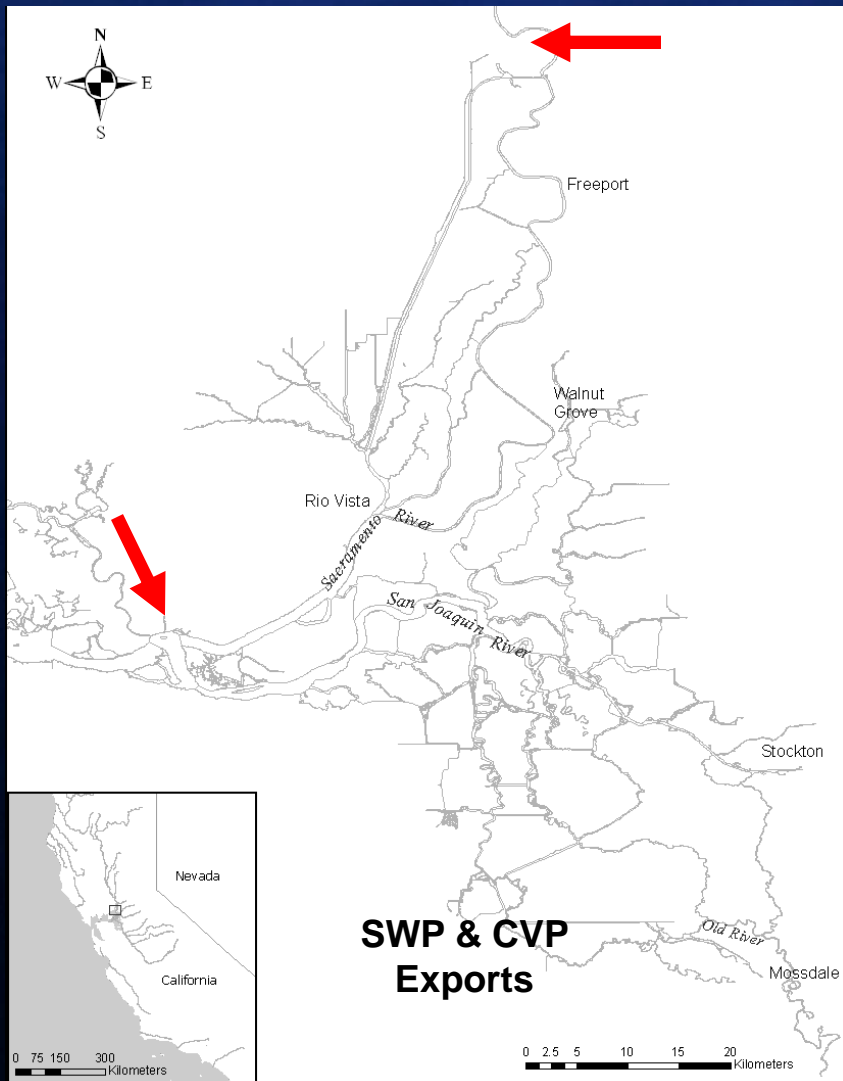Species: Winter run Chinook salmon

Life stages: Adult to Parr

Location: Upriver to Mid-river

Physical Inputs: Daily river flow (CALSIM II $\rightarrow$ USRDOM)
                  Daily river flow (USRDOM $\rightarrow$ USRWQM)

Conservation Measures: Modify survival functions

Models Related to Operations and RPAs

- Delta Passage Model (DPM)

SWP & CVP
Exports

Species: Winter, Spring and Fall
run Chinook

Life stages: parr to smolt

Location: Mid-river to Bay

Physical Inputs:
reach-specific daily flow (DSM2 Hydro)
daily exports (CALSIM II)
daily gate operations (CALSIM II)

Conservation Measures: Modify survival
functions and/or fish route selection

Models Related to Operations and RPAs

So we have JPE and DPM models…

…then what is IOS?

Models Related to Operations and RPAs

IOS = JPE + DPM + Ocean

– Integrative Object-oriented Salmon Simulation (IOS)

– Assimilates available information and integrates effects across life stages and through years

– An Individual-oriented model (but not IBM)
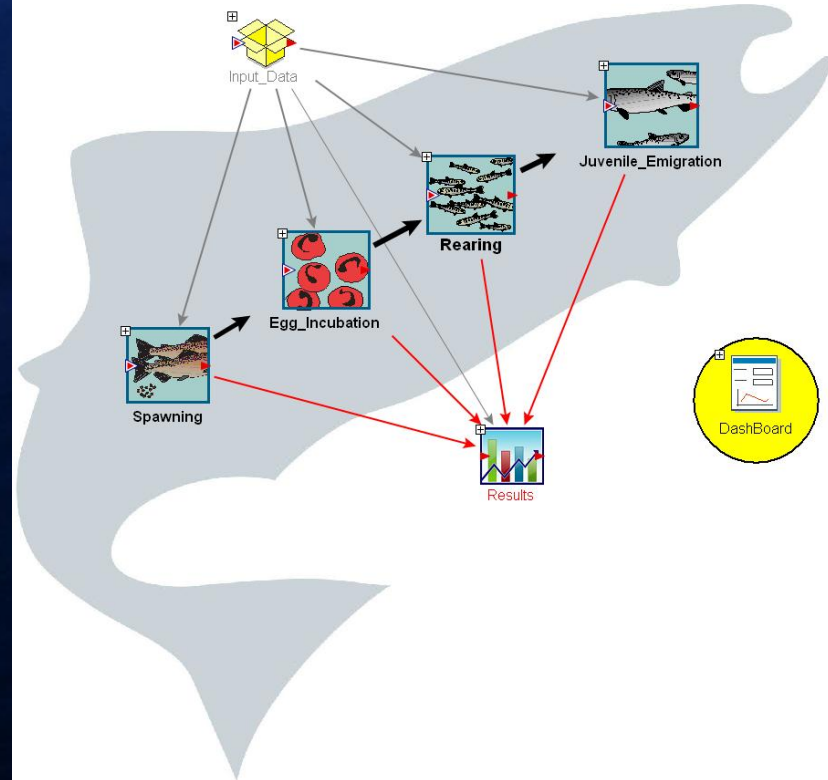
– Only winter run Chinook salmon (currently)
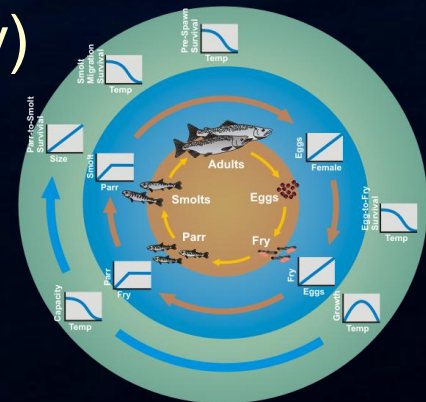
The JPE Model

- Simulation based model, puts together a series of statistical models and relationships

- Individual cohorts of fish experience daily time steps

Sacramento River Winter Chinook Salmon Juvenile Production Model
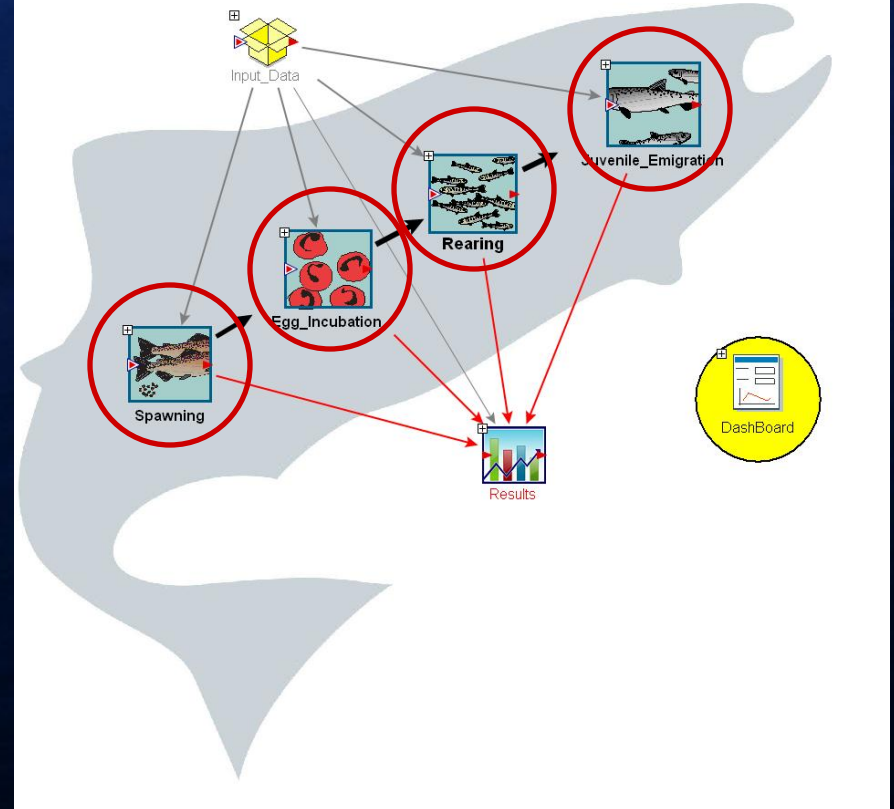
The JPE Model

- Four main components of the JPE

  1) Spawning

  2) Egg Incubation

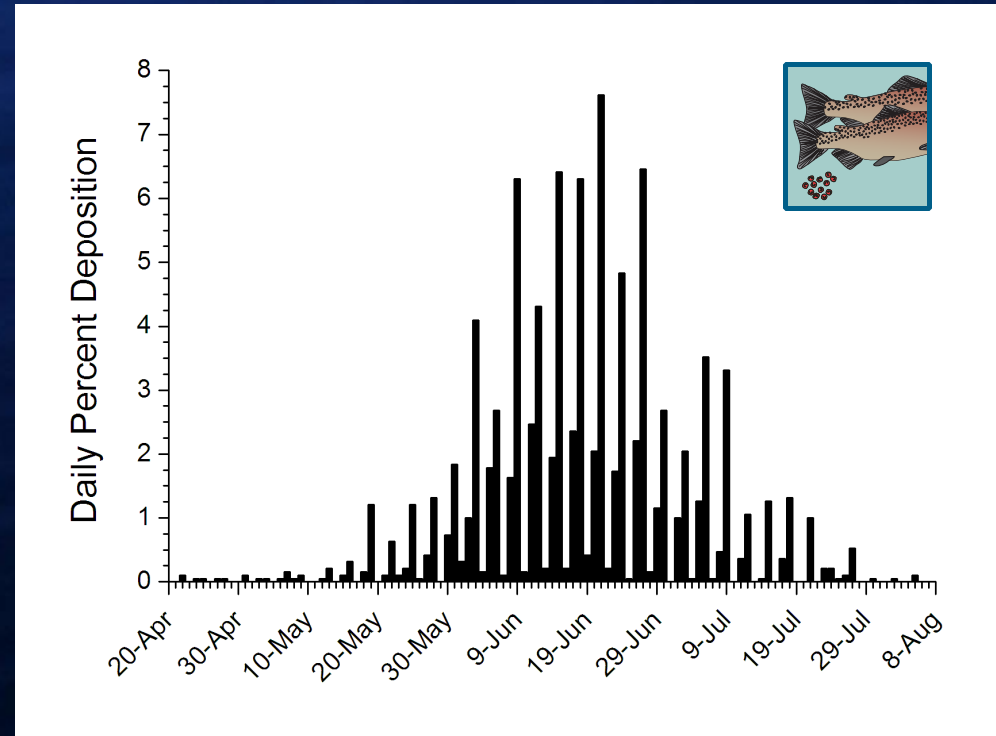 3) Rearing

  4) Juvenile Emigration

Sacramento River Winter Chinook Salmon Juvenile Production Model

JPE Model Description

- ## Spawning Distribution

  - ### Used daily carcass counts to determine spawning distribution

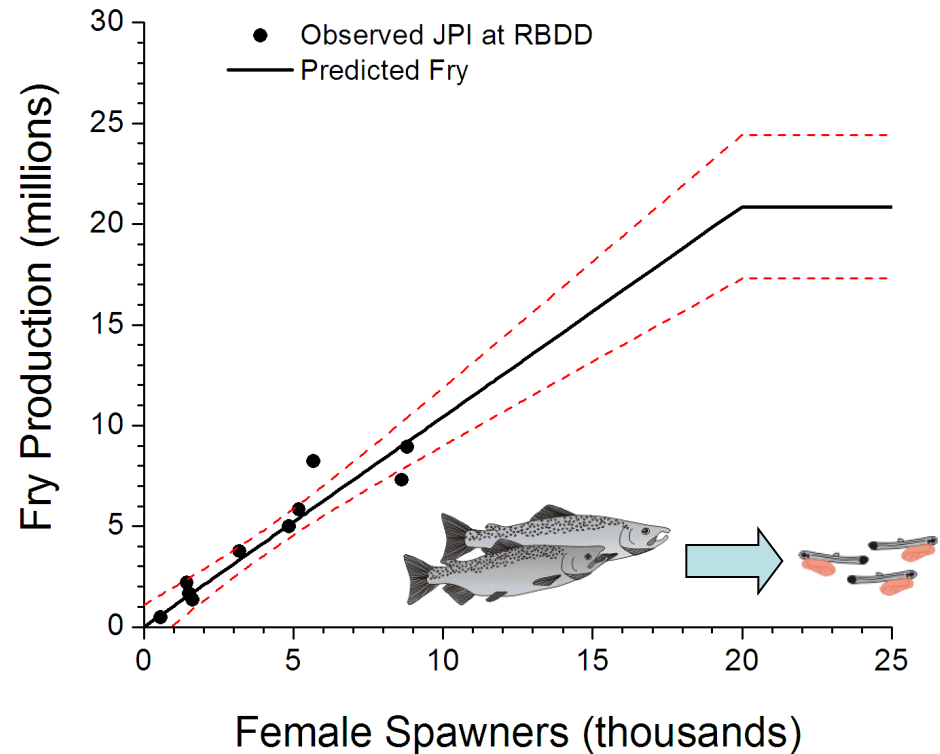 - ### Timing shifted 14 days prior to carcass observations

Data: *Doug Killam Carcass Survey data*

JPE Model Description

- ## Stock-Recruitment

  - ### *Stock*: number of female spawners from carcass surveys

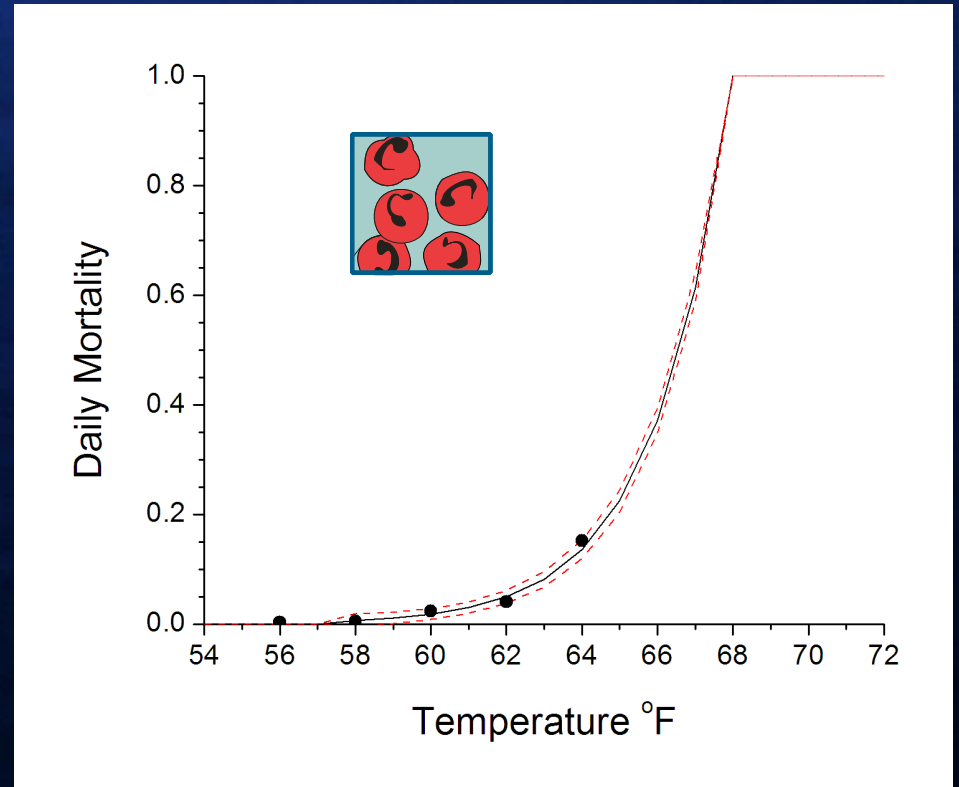 - ### *Recruitment*: fry equivalent at RSTs

Data: *Poytress and Carillo, USFWS Reports*

JPE Model Description

- Egg Mortality
  - Fertilization to Emergence
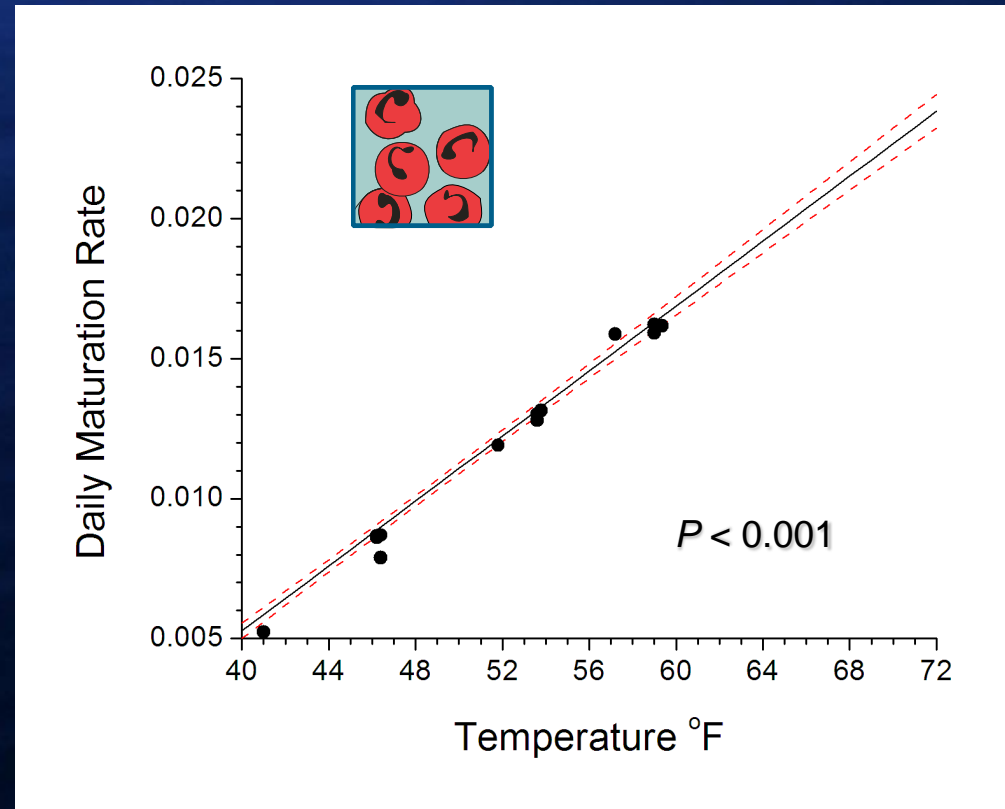 - Applied mortality to cohorts when temps go beyond 57°F

Data from: *USFWS 1999*

JPE Model Description

- Egg Maturation
  - Fertilization to Emergence
  - Ran regression and derived predicted values from experimental data
  - Standard errors derived from regression analysis
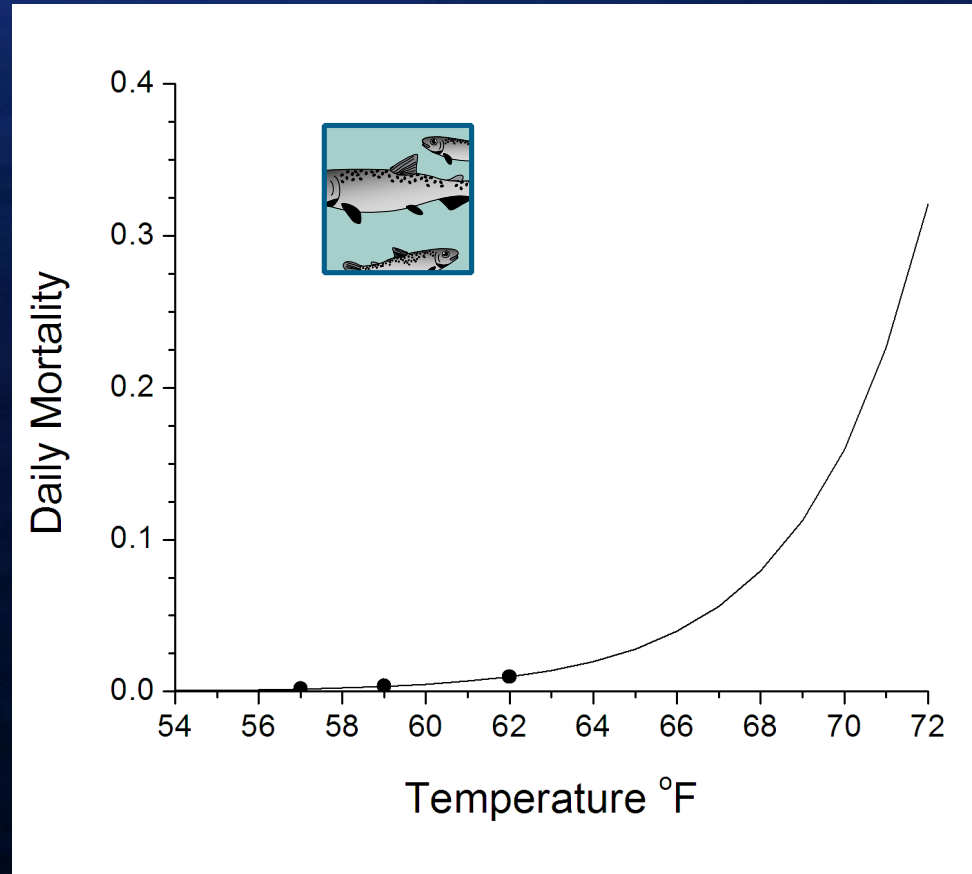 - *Relationship used to inform daily time step*

$P < 0.001$

Data from: *USFWS 1999*

JPE Model Description
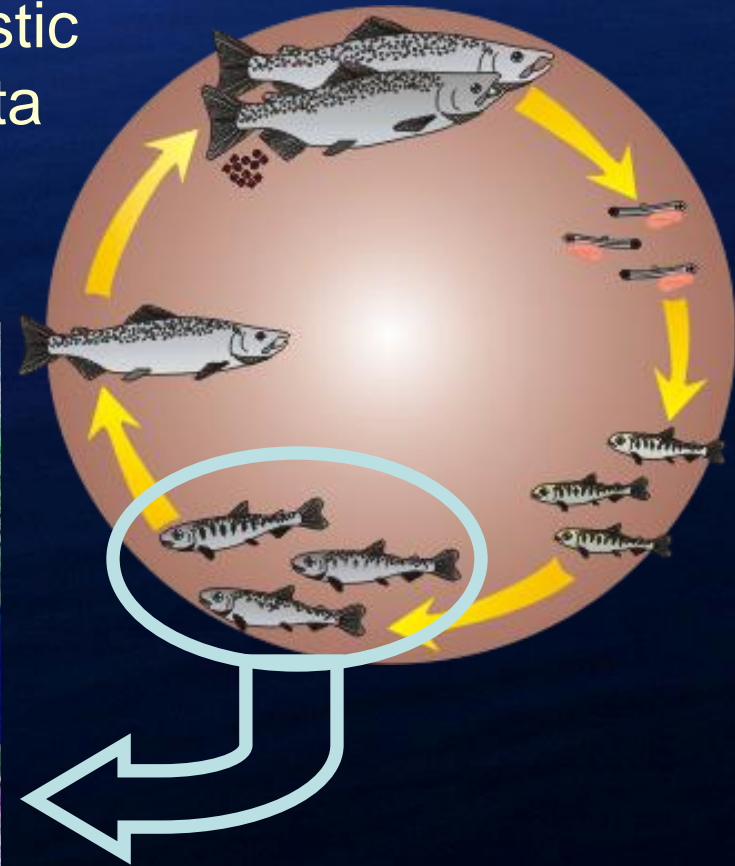
- Rearing mortality
  - Fry to smolt stage
  - Smolts considered >75mm
  - Applied mortality to cohorts on a daily time step

Data from: *USFWS 1999*
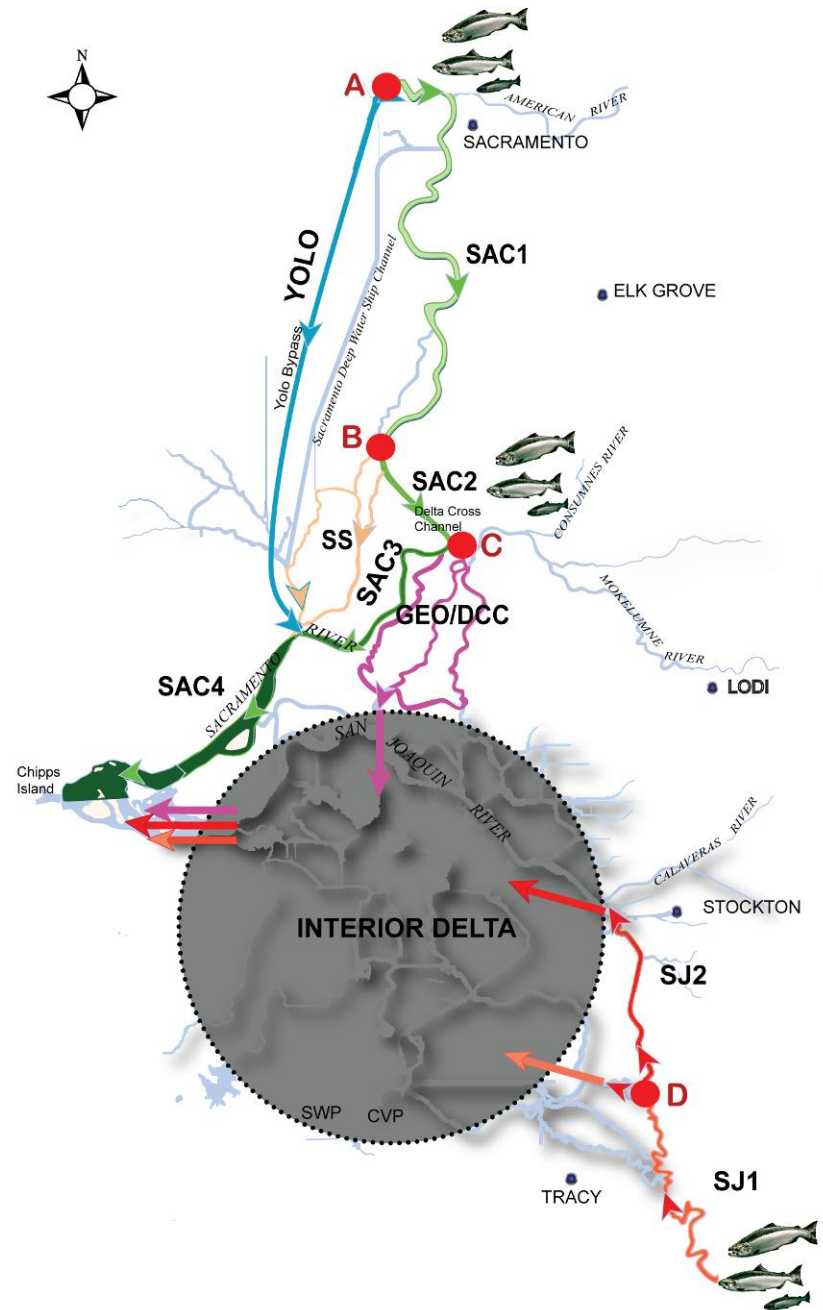
Delta Passage Model (DPM)

Integrates and applies best available empirical data from analyses of acoustic and coded wire tag studies in the Delta
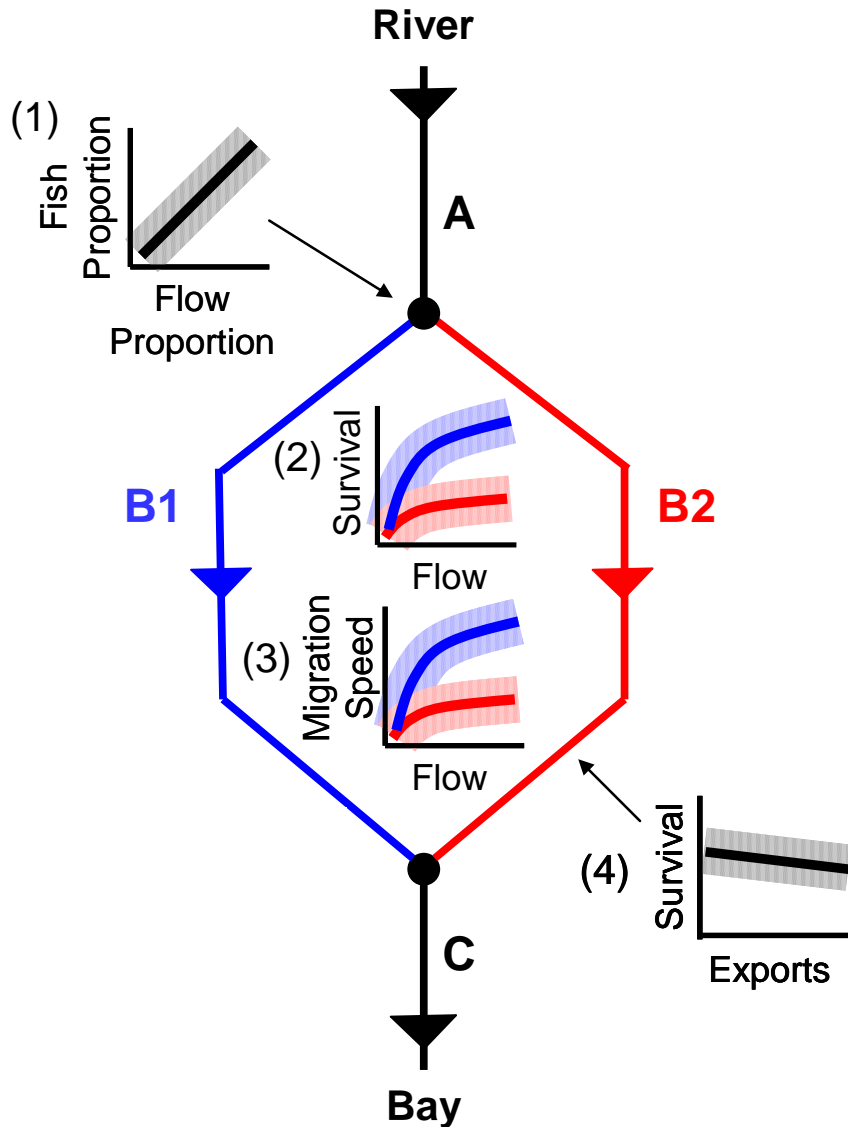
Delta Passage Model (DPM)

Operates on a daily time step, using daily average flows (DSM2 Hydro) for primary migration routes

Most functional relationships structured as probability distributions

DPM Conceptual Model

Critical DPM Information Sources

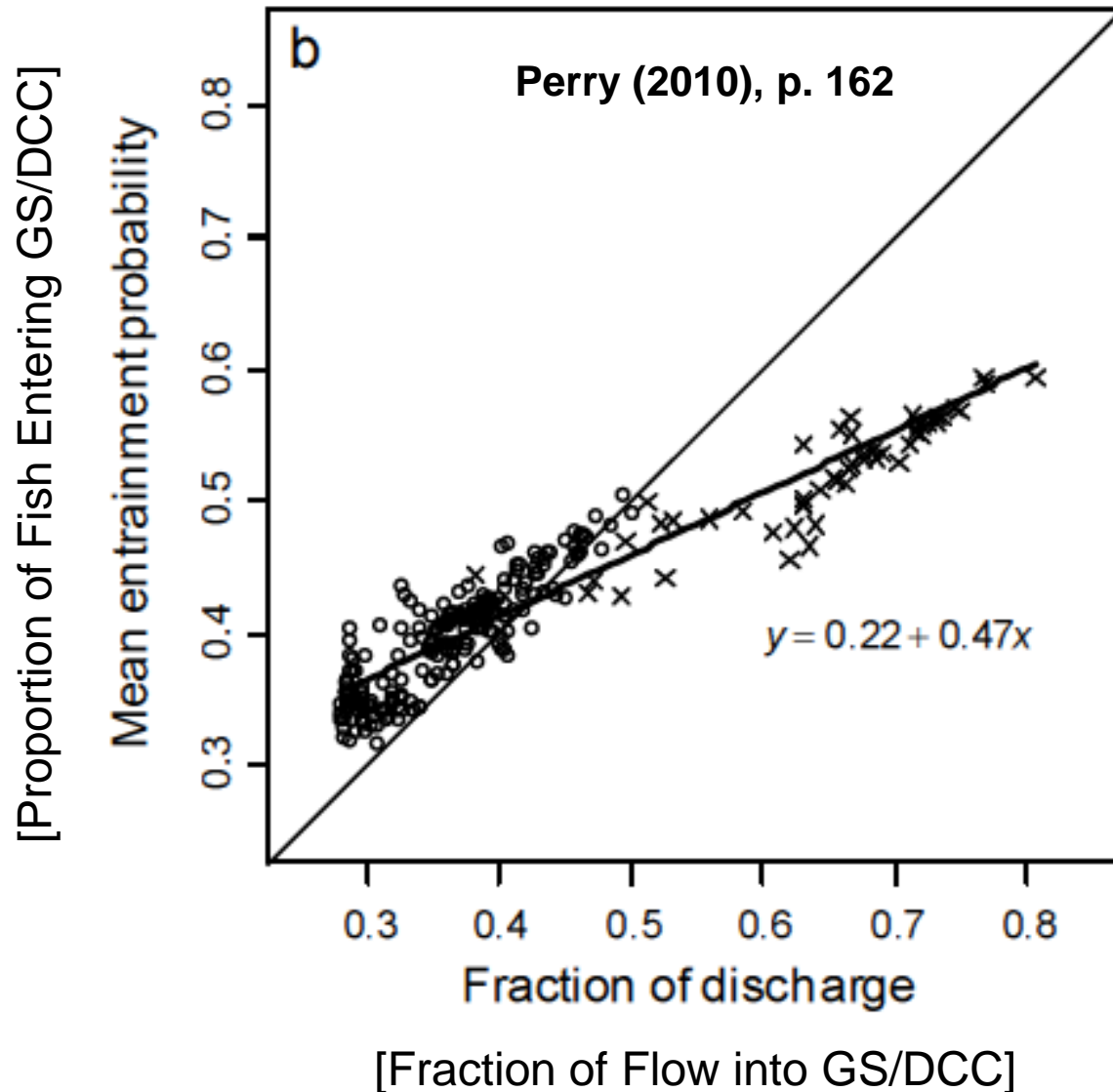| Major Function	Primary Sources	Method Description
(1) Route seleciton at junctions	Perry (2010); Holbrook et al. 2009	Analysis of acoustically tagged smolts in the North Delta
(2) Reach-specific survival	a) Burau et al. 2007; SJRGA 2009; Perry 2010	a) Reach-specific survival estimates from acoustically tagged smolts in the Delta
	b) Newman and Rice 2002; Newman 2003, Newman 2008	b) Statistical analysis of coded-wire tagged smolts
(3) Migration speed	Vogel 2008	Migration speed of acoustically tagged smolts in the North Delta
(4) South Delta export mortality	Newman and Brandes 2009	Analysis of coded-wire tagged smolts

DPM Functional Relationships
Flow-survival (Sacramento River Routes)
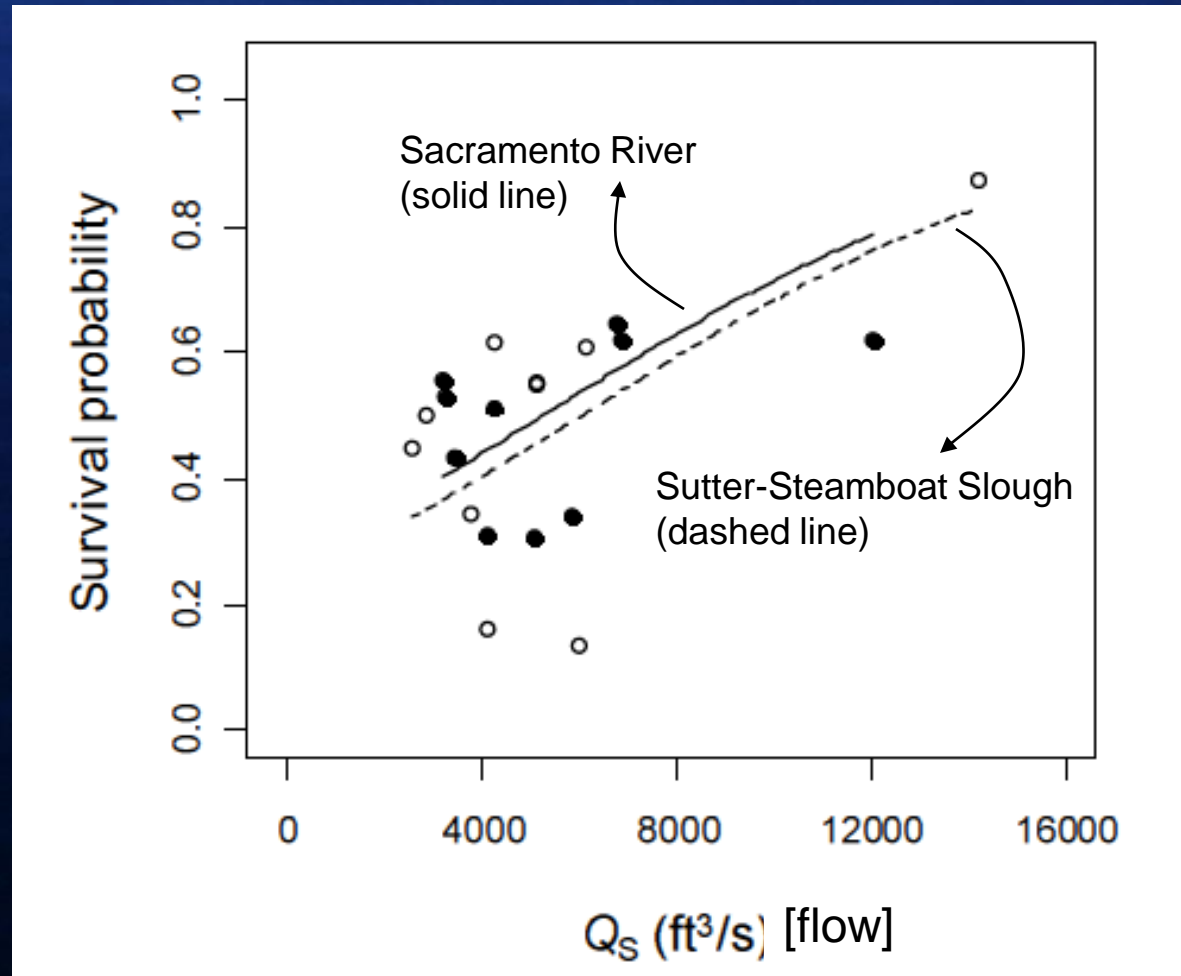
from Perry (2010), p.128

DPM Functional Relationships
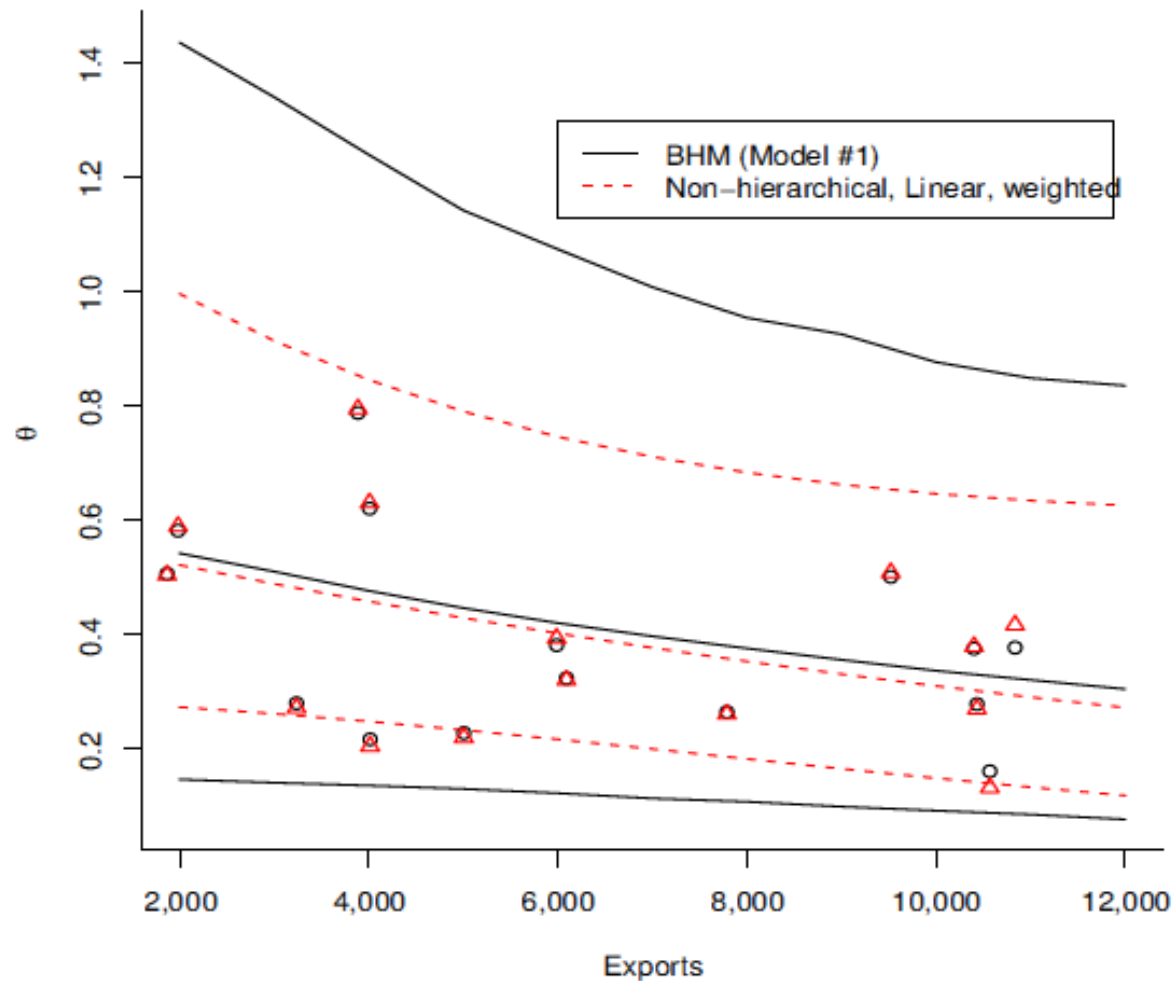## Fish route allocation at Georgiana Slough/DCC

b

Perry (2010), p. 162

[Proportion of Fish Entering GS/DCC]

Mean entrainment probability

$y = 0.22 + 0.47x$

Fraction of discharge

[Fraction of Flow into GS/DCC]

DPM Functional Relationships
Export mortality Georgiana Slough

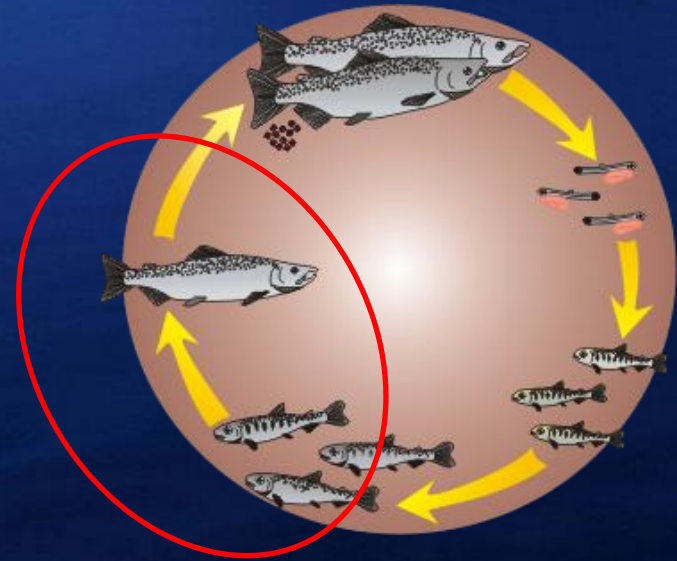Newman and Brandes 2009, p. 35

Ocean

- Not directly related to water project operations or NMFS RPAs (as proposed in 2009 BiOp), but…

  - Important for context

  - Necessary for life cycle model

  - Necessary to account for population effects resulting from inland management actions
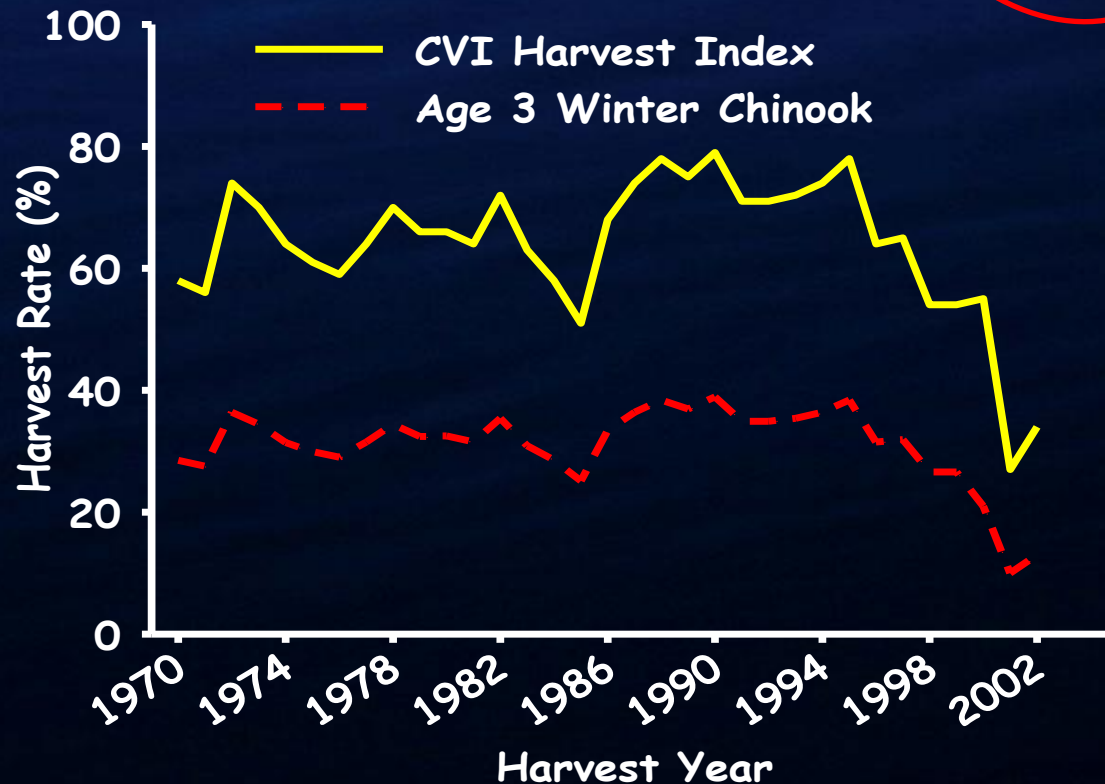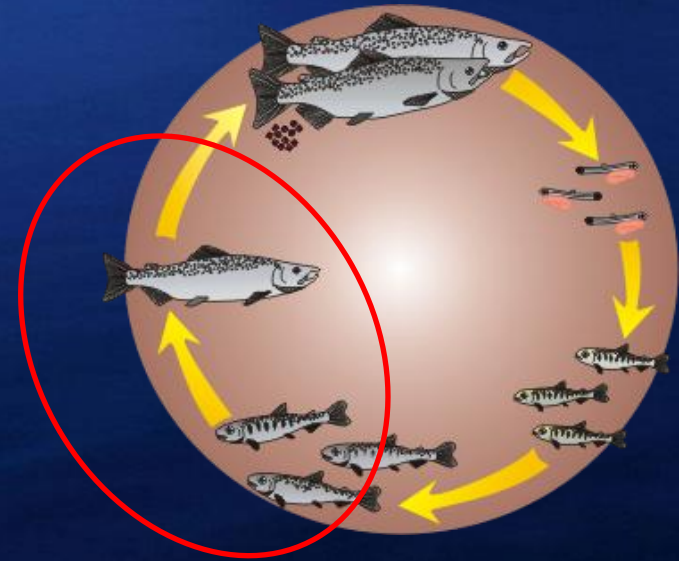
Ocean

- ## Smolt to Age-2 Survival
  - 2% to 6% (stochastic uniform distribution)

- ## Age-2 Survival
  - 2% to 34% (auto-correlated stochastic survival scalar based on Wells Index)

Wells Index (standardized) Survival Scalar
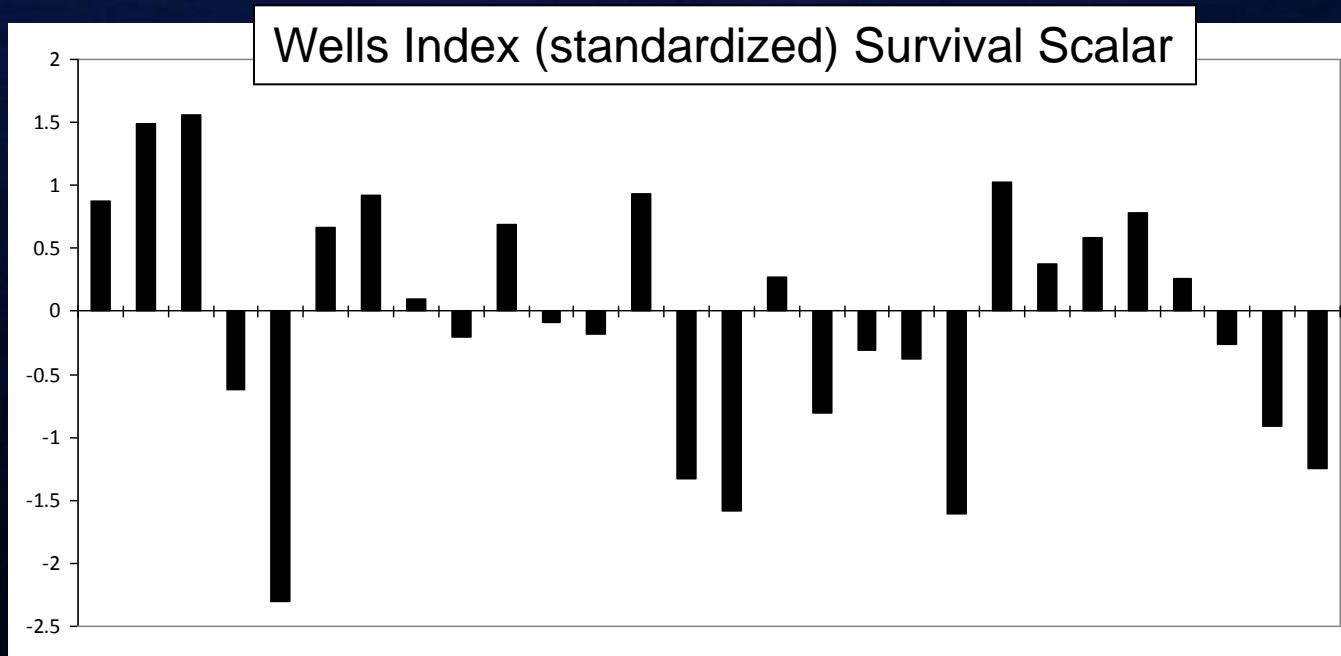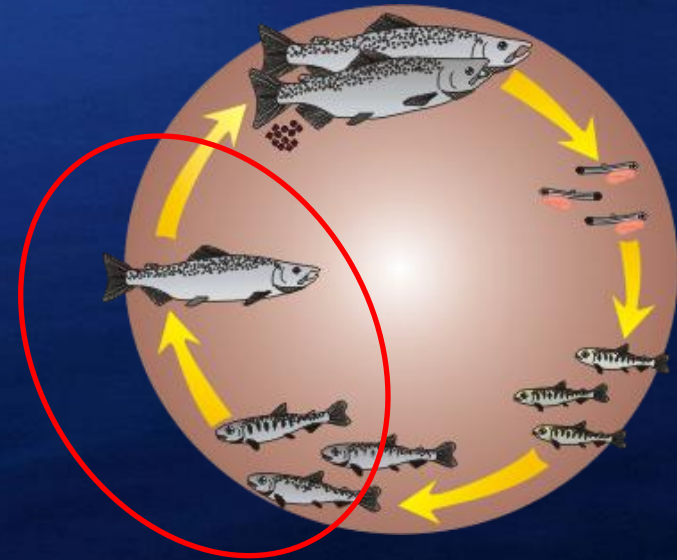
Ocean

- Age-3 Survival
  - 20% (constant)
- Age-3 Harvest Mortality
  - 0% to 39% (stochastic, uniform distribution)

Model Applications

IOS
- OCAP Biological Assessment
- BDCP
- North-of-Delta Off-stream Storage (in progress)

DPM
- OCAP BiOp evaluations
- Two-Gates Project
- BDCP
- North-of-Delta-Offstream-Storage (in progress)
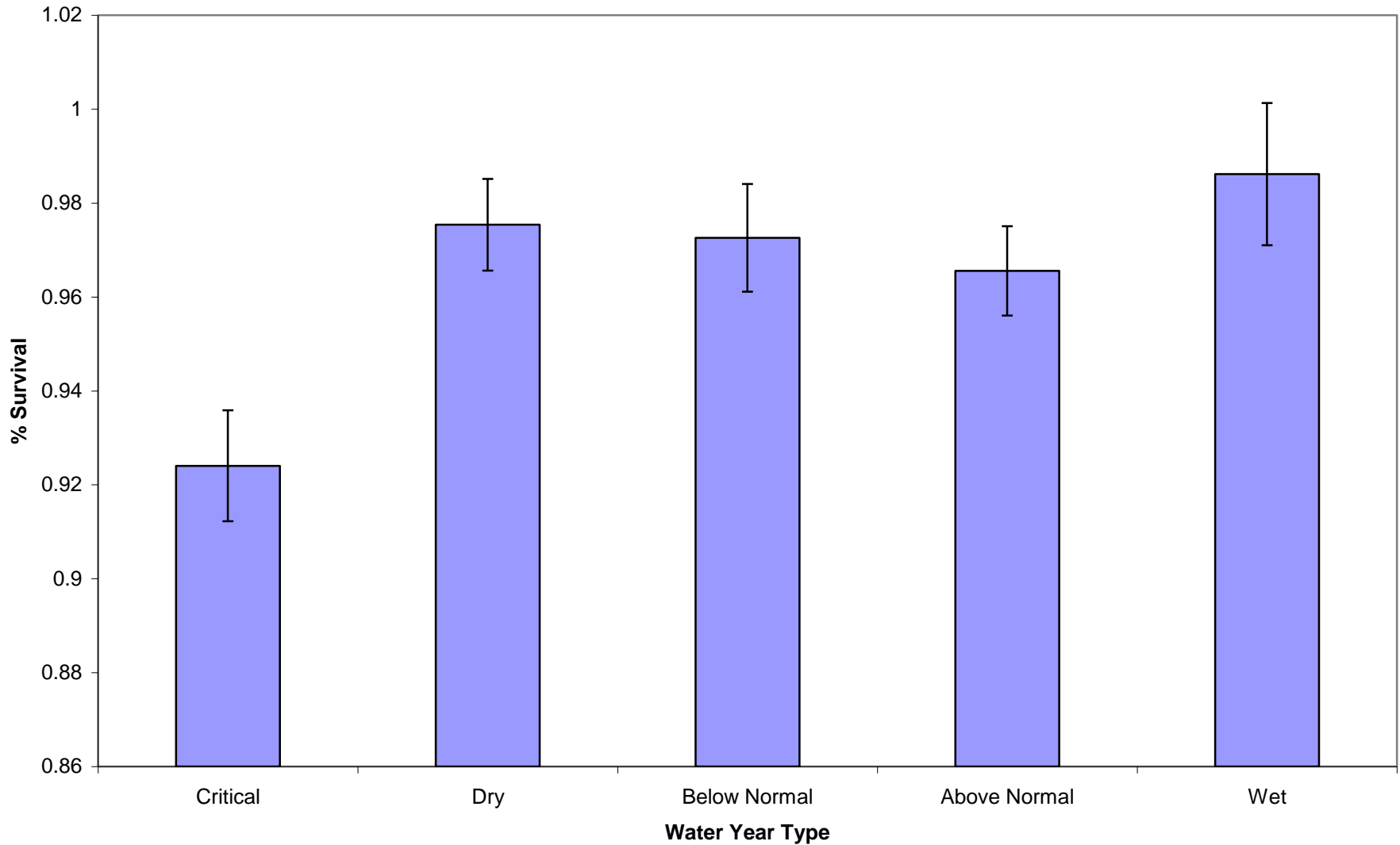- Franks Tract Project (future)

Model Results

- Example of how model results commonly reported
- But for understanding how the model works, sensitivity analysis is more useful
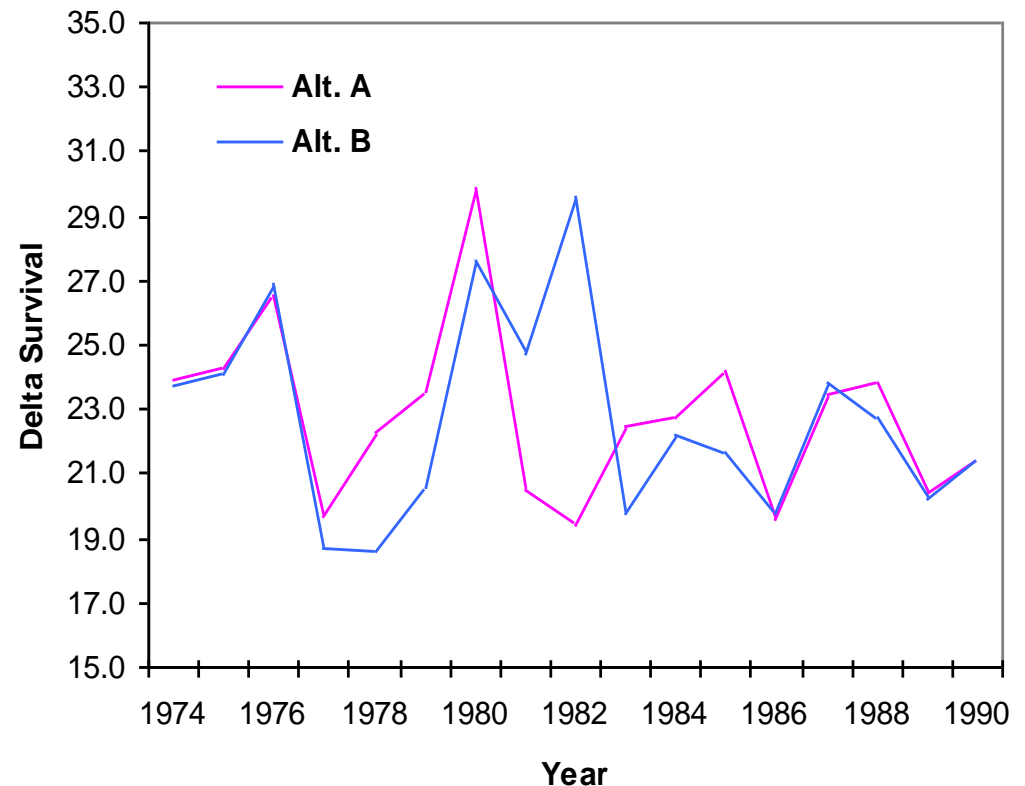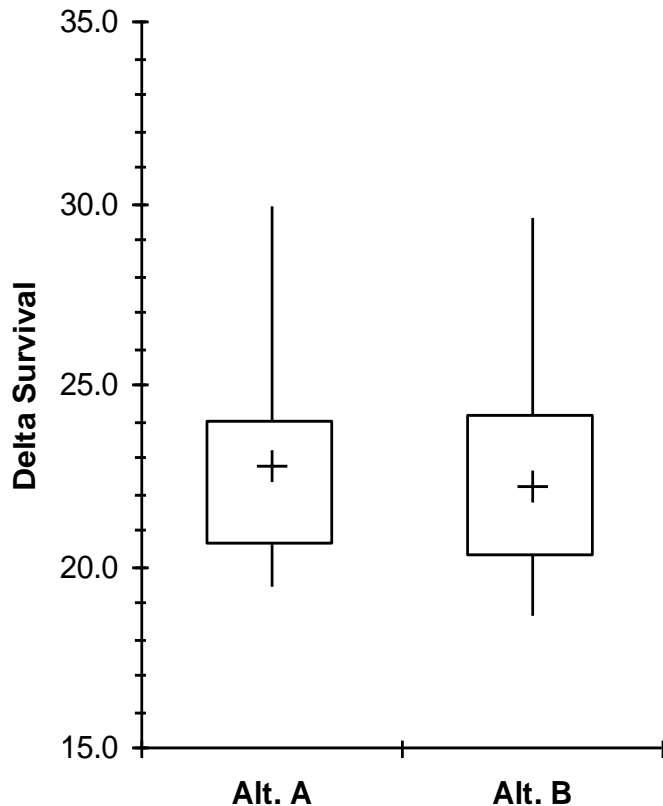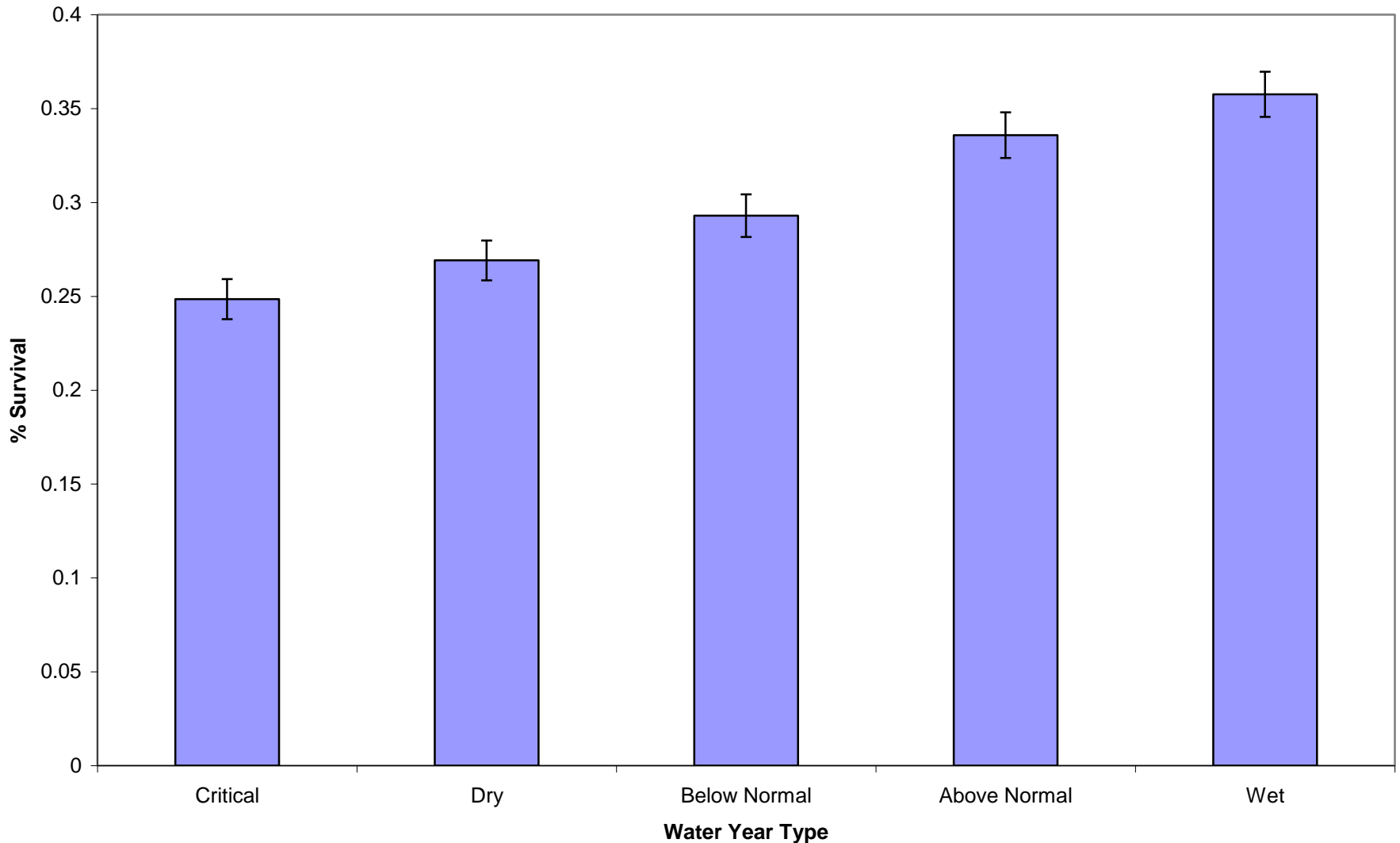
Sensitivity Analysis: Water Year Type
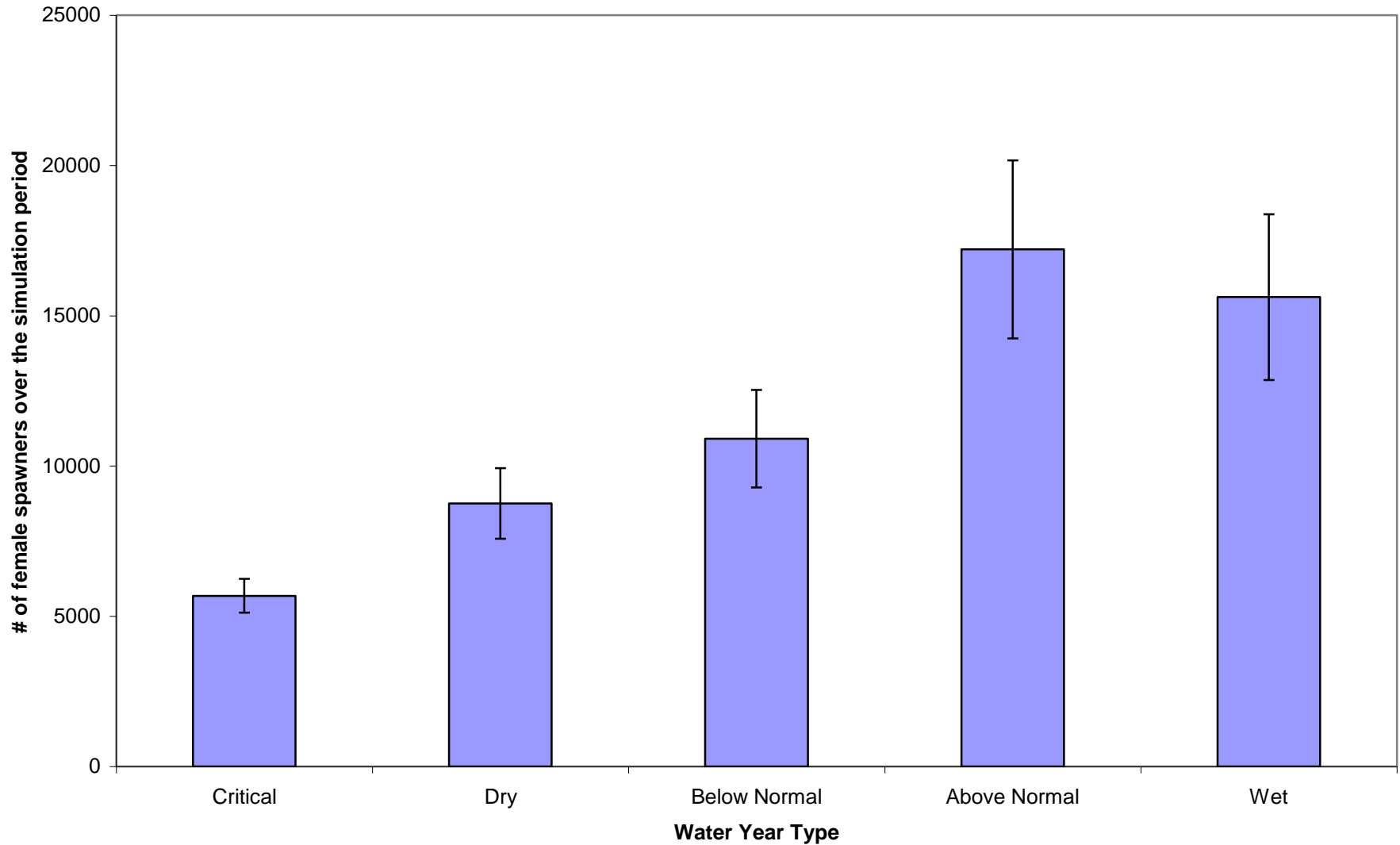

Egg to Fry Survival by Water Year

Sensitivity Analysis: Water Year Type
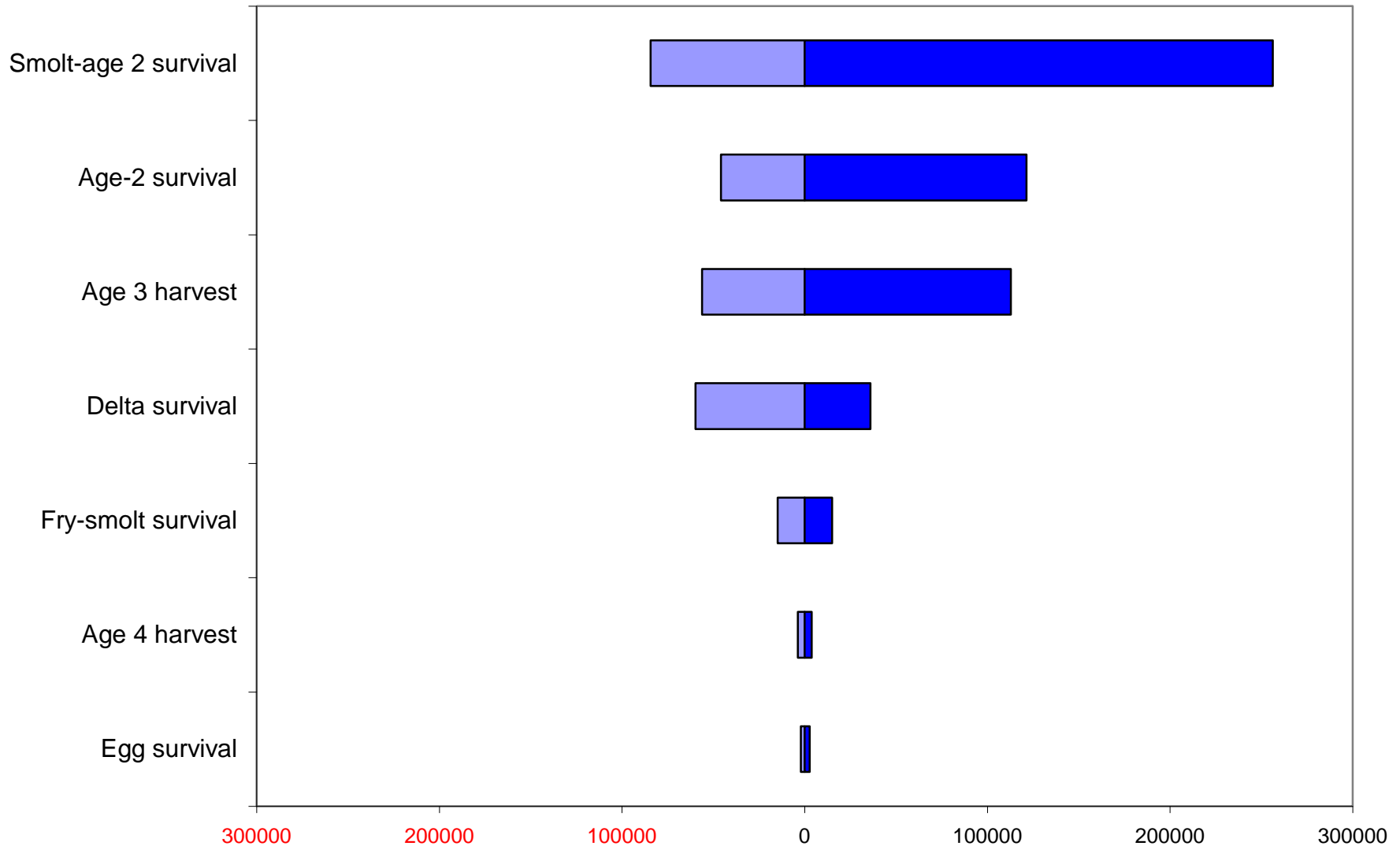

Delta Survival by Water Year

Sensitivity Analysis: Water Year Type

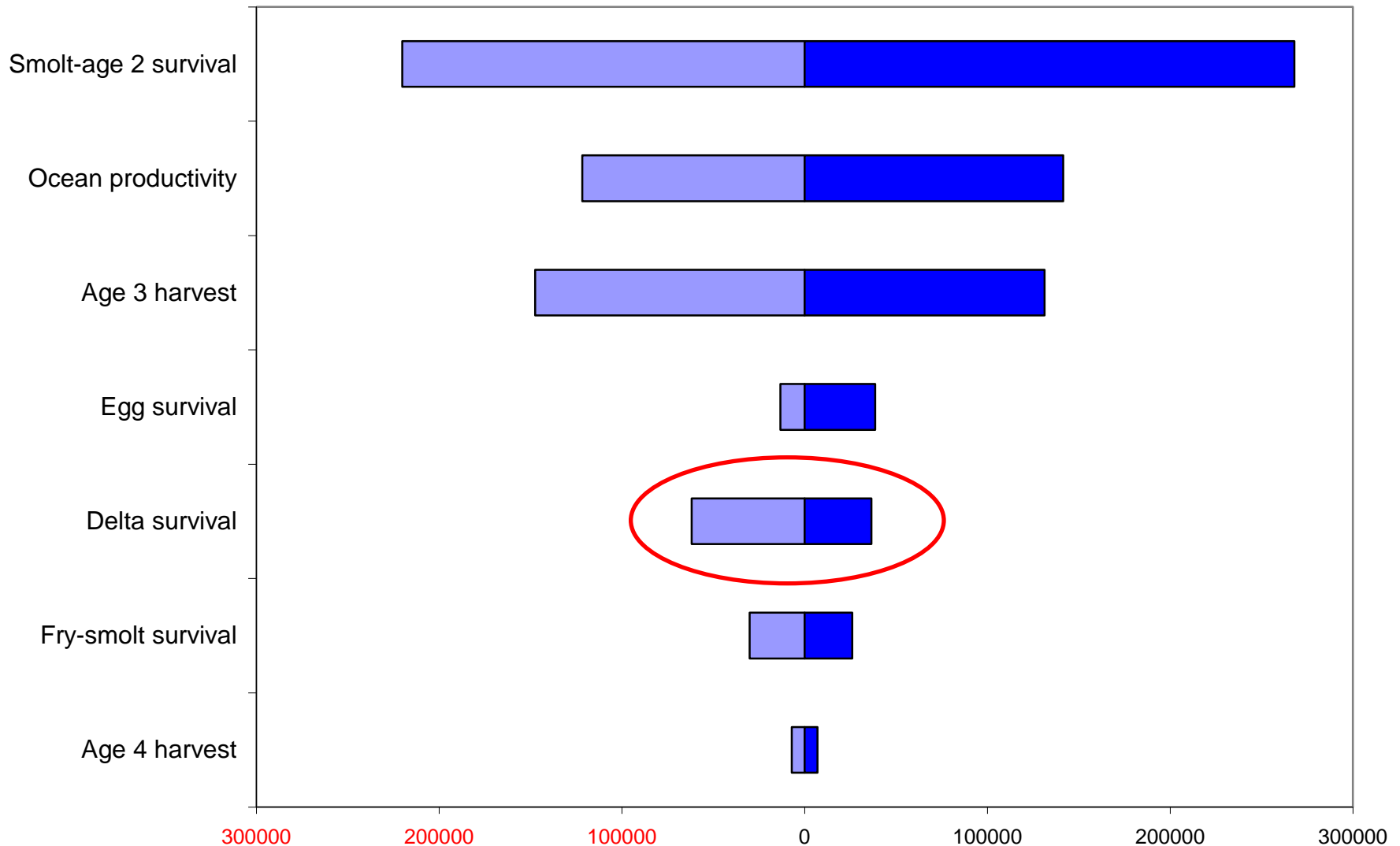Spawning Escapement by Water Year

Sensitivity Analysis: Life Stage Functions

Change in Spawners: "Dry" Water Year
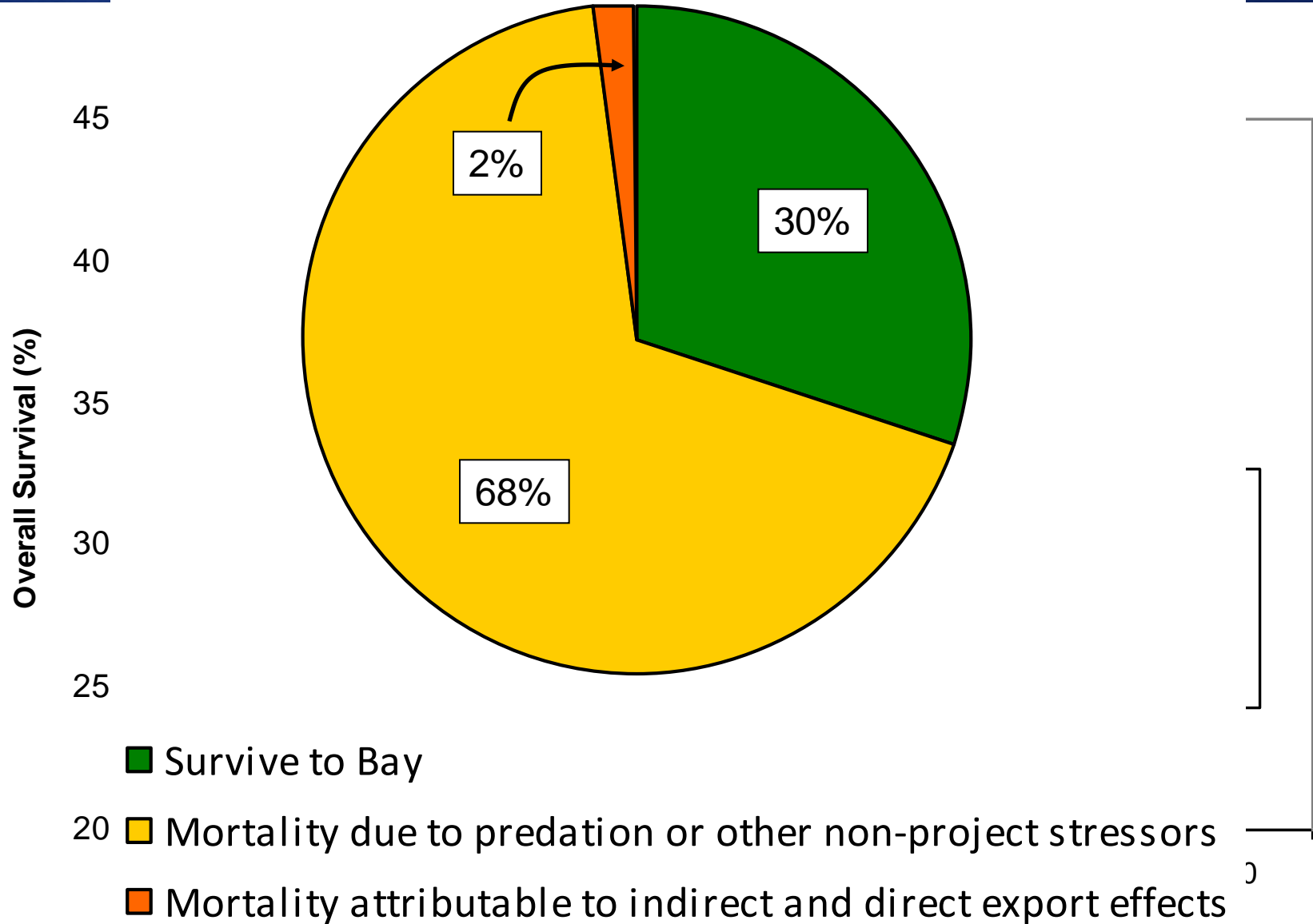
Sensitivity Analysis: Life Stage Functions
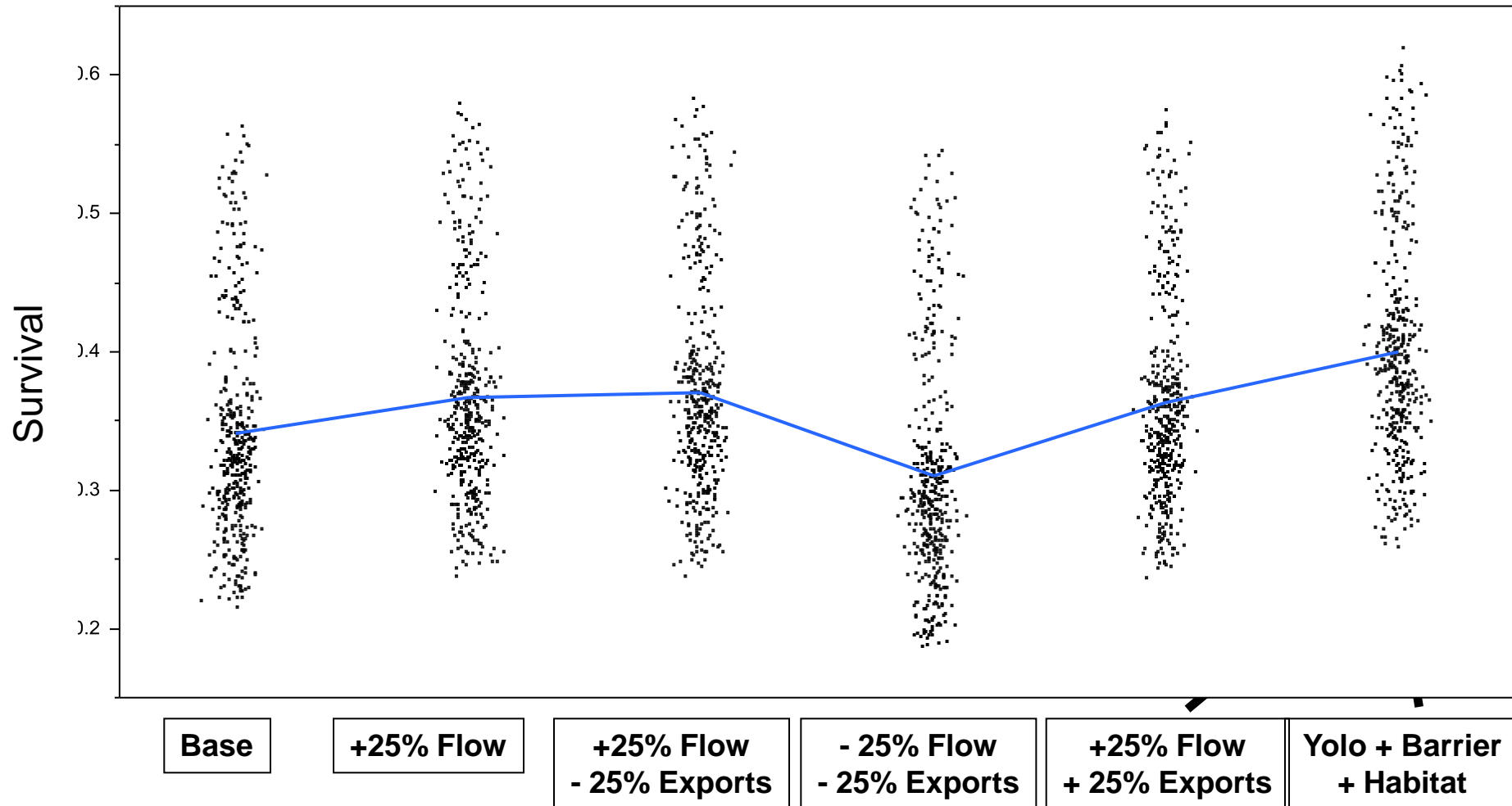

Change in Spawners: "Wet" Water Year

Sensitivity Analysis: Delta Survival

Example Application: Gaming Potential Management Actions

Delta Survival (probabilistic simulations)

Overall Conclusions

- Simulation models can be useful for integrating available science and telling us what matters most

- What is IOS telling us?
  - Water year type is an important driver
    - manage *for* inflows, temperatures, and improved Delta habitat?
    - *less* emphasis on exports?
  - Ocean factors are huge
    - but we only control harvest

How do we know the simulation model is "right"?

- Validation?
  - Not feasible for most simulation models
- What can we do?
  - Calibrate and test model components with empirical data
  - Carefully review and critique underlying logic
  - Explore and test model sensitivity
  - Include uncertainty in model

Critical Uncertainties

- Survival-flow effect
  - Some analyses show positive flow effect, but thresholds and mechanisms uncertain
    - decreased residence time (due to higher velocities) or decreased predator efficiency (due to turbidity)?
- Contribution of different life history strategies
  - fry emigrants vs. smolts

What next?

- Preparing IOS manuscript
- Model enhancements underway
  - Floodplain use, capacity and benefits
  - Refined use of DSM2 Hydro for fish route selection and survival
- Continue and expand collaborations with resource agency biologists